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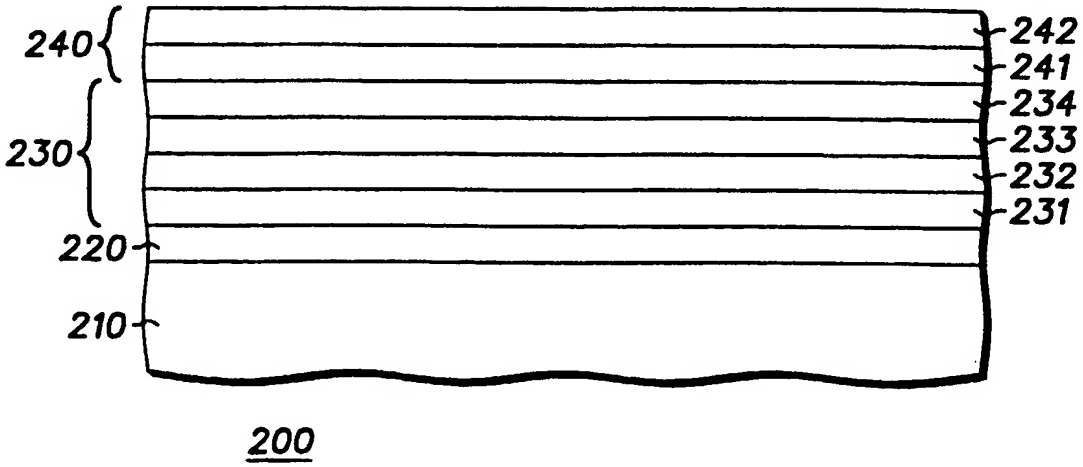
(54) Title: SEMICONDUCTOR COMPONENT AND METHOD OF MANUFACTURING



(57) Abstract: A method (100) of manufacturing a semiconductor component includes growing a doped silicon germanium: carbon (SiGe:C) epitaxial layer (230) over a semiconductor substrate (210). The method also includes annealing the epitaxial layer and using the carbon in the epitaxial layer to control diffusion of the germanium in the epitaxial layer during the annealing step.

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SEMICONDUCTOR COMPONENT AND METHOD OF MANUFACTURING

Field of the Invention

This invention relates, in general, to electronics, and more particularly, to semiconductor components and methods of manufacture.

Background of the Invention

Doped epitaxial layers comprised of silicon, germanium, and carbon are used as base regions for heterojunction bipolar transistors (HBTs). These epitaxial layers are typically grown by complicated, costly, and time consuming processes. Accordingly, a need exists for a semiconductor component and method of manufacturing that keeps the cost and complexity of the manufacturing process at a minimum, that does not have a low manufacturing throughput, and that facilitates the matching of different epitaxial growth reactors.

Brief Description of the Drawings

The invention will be better understood from a reading of the following detailed description, taken in conjunction with the accompanying drawing figures in which:

FIG. 1 outlines a method of manufacturing a semiconductor component in accordance with an embodiment of the invention;

FIG. 2 illustrates a cross-sectional view of a portion of a semiconductor component in accordance with an embodiment of the invention; and

FIGs. 3 and 4 illustrate distribution profiles of germanium in an epitaxial layer of the semiconductor component in accordance with an embodiment of the invention.

For simplicity and clarity of illustration, the drawing figures illustrate the general manner of construction, and descriptions and details of well-known features and techniques are omitted to avoid unnecessarily obscuring the invention. Additionally, elements in the drawing figures are not necessarily drawn to scale, and the same reference numerals in different figures denote the same elements.

Furthermore, the terms first, second, third, fourth, and the like in the description and in the claims, if any, are used for distinguishing between similar elements and not necessarily for describing a sequential or chronological order. It is further understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in sequences other than those described or illustrated herein.

Moreover, the terms top, bottom, over, under, and the like in the description and in the claims, if any, are used for descriptive purposes and not necessarily for describing relative positions. It is understood that the terms so used are interchangeable under appropriate circumstances.

Detailed Description of the Drawings

FIG. 1 outlines a method 100 of manufacturing a semiconductor component. As an example, the semiconductor component can be a discrete, vertical HBT. As another example, the semiconductor component can be an integrated circuit (IC) having at least one HBT. The IC can be a bipolar IC or a bipolar complimentary metal-oxide-semiconductor (BiCMOS) IC.

In a step 105 of method 100, a substrate is provided. As an example, the substrate can be comprised of a semiconductor material. In the preferred embodiment, the substrate is comprised of crystalline silicon. However, in an alternative embodiment, the substrate can be comprised of gallium arsenide or silicon carbide.

In a step 110 of method 100, the substrate is loaded or inserted into an epitaxial growth reactor. As an example, the epitaxial growth reactor can be a reduced pressure chemical vapor deposition (RPCVD) epitaxial reactor. In the preferred embodiment, the epitaxial growth reactor is an E2000 reactor commercially available from Advanced Semiconductor Materials (ASM) America, Inc. of Phoenix, Arizona.

The reactor is used to grow several epitaxial layers over the substrate. In the preferred embodiment, the epitaxial layers are grown within a single chamber of the reactor at a pressure of approximately 70 to 90 Torr. However, in an alternative embodiment, the epitaxial layers can be grown within different chambers of a different reactor. In another embodiment, the epitaxial layers can be grown within different chambers of different reactors.

Before growing the first epitaxial layer in the chamber of the reactor, the chamber is prepared for the epitaxial growth process. As an example, the chamber can be heated and cleaned before step 110 is performed. The cleaning process can involve etching the chamber for several seconds. After step 110 is performed, the substrate can be prepared for epitaxial growth by baking the substrate for approximately 1 to 3 minutes at approximately 900 to 950 degrees Celsius.

In a step 115 of method 100 in FIG. 1, a first epitaxial layer is grown over the substrate in a chamber of the epitaxial growth reactor. The first epitaxial layer serves as a buffer layer between the substrate and a subsequently grown second epitaxial layer. As an example, the first epitaxial layer can be comprised of a semiconductor material such as silicon and can be undoped. The first epitaxial layer can be grown at a rate of approximately 0.1 to 0.4 nanometers per second to a thickness greater than approximately 1 nanometer. The first epitaxial layer can be grown at a temperature of approximately 690 to 710 degrees Celsius.

In the preferred embodiment, the first epitaxial layer is grown on the substrate to consist essentially of silicon. The first epitaxial layer can be grown from a silicon gas source such as silane, disilane, or dichlorosilane. Also in the preferred embodiment, the first epitaxial layer is grown to be substantially devoid of a dopant. Further in the preferred embodiment, the first epitaxial layer has a thickness of approximately 40 to 60 nanometers.

Next, a second epitaxial layer is grown over the first epitaxial layer at steps 120-135. The second epitaxial layer serves as a base region for an NPN HBT in the semiconductor component. The second epitaxial layer is comprised of a semiconductor material different from the first epitaxial layer to create a heterojunction between the first and second epitaxial layers. In the preferred embodiment, the second epitaxial layer is comprised of silicon, germanium, carbon, and a p-type dopant, but only a portion of the second epitaxial layer contains the p-type dopant. In an alternative embodiment, the p-type dopant can be replace by an n-type dopant. The concentration of germanium in the second epitaxial layer is grown at different constant levels within the second epitaxial layer. As an example, the chemical formula for the second epitaxial layer can be $Si_{1-x}Ge_x$:C, and the p-type dopant can be boron.

The carbon in the second epitaxial layer serves two purposes. First, the carbon decreases the diffusion length of the boron in the second epitaxial layer. Second, the carbon increases the diffusion length of the germanium in the second epitaxial layer. The carbon enhances the germanium diffusion by creating a local vacancy supersaturation within the lattice structure of the second epitaxial layer.

The concentration of carbon in the second epitaxial layer can be grown at different levels within the second epitaxial layer to control the diffusion of the boron and germanium in the second epitaxial layer. For instance, the concentration of the carbon can be decreased or increased within the second epitaxial layer. As an example, the carbon concentration may vary with depth within the second epitaxial layer.

However, in the preferred embodiment, the concentration of carbon is grown to be substantially constant within the entire second epitaxial layer. Also in the preferred embodiment, the second epitaxial layer is referred to as a silicon germanium: carbon (SiGe:C) layer, and not as a silicon germanium carbide (SiGeC) layer. The reason for this difference in nomenclature is because the amount of carbon in the second epitaxial layer is so low that the second epitaxial layer does not have the expected properties of a silicon carbide film.

At a step 120 of method 100 in FIG. 1, a first portion of the second epitaxial layer is grown over the first epitaxial layer in the chamber of the epitaxial growth reactor. The first portion of the second epitaxial layer is comprised of silicon, germanium, and carbon. The first portion of the second epitaxial layer can be grown at a rate of approximately 0.1 to 0.2 nanometers per second and can have a thickness of greater than approximately 1 nanometer. The first portion of the second epitaxial layer can be grown at a temperature of approximately 590 to 650 degrees Celsius.

In the preferred embodiment, the first portion of the second epitaxial layer is grown on the first epitaxial layer to consist essentially of silicon, germanium, and carbon. The first portion of the second epitaxial layer can be grown from a silicon gas source such as silane, disilane, or dichlorosilane, a germanium gas source such as hydrogen germane, and a carbon gas source such as methylsilane. Also in the preferred embodiment, the first portion of the second epitaxial layer is grown to be substantially devoid of the p-type dopant, to have a substantially constant concentration of

germanium, and to have a substantially constant concentration of carbon. As an example, the first portion of the second epitaxial layer can have a constant germanium concentration of approximately 20 to 25 percent and can also have a constant carbon concentration of less than approximately 0.1 percent to approximately 0.3 percent. In the preferred embodiment, the first portion of the second epitaxial layer has a thickness of approximately 10 to 12 nanometers.

At a step 125 of method 100 in FIG. 1, a second portion of the second epitaxial layer is grown over the first portion of the second epitaxial layer in the chamber of the epitaxial growth reactor. The second portion of the second epitaxial layer is comprised of silicon, germanium, carbon, and the p-type dopant. As indicated earlier, the p-type dopant can be replaced by an n-type dopant. The second portion of the second epitaxial layer can be grown at a rate of approximately 0.1 to 0.2 nanometers per second and can have a thickness of greater than approximately 1 nanometer. The second portion of the second epitaxial layer can be grown at a temperature of approximately 590 to 650 degrees Celsius.

In the preferred embodiment, the second portion of the second epitaxial layer is grown on the first portion of the second epitaxial layer to consist essentially of silicon, germanium, carbon, and the p-type dopant. The second portion of the second epitaxial layer can be grown from a silicon gas source such as silane, disilane, or dichlorosilane, a germanium gas source such as hydrogen germane, a carbon gas source such as methylsilane, and a p-type dopant gas source such as diborane. Also in the preferred

embodiment, the second portion of the second epitaxial layer is grown to have a substantially constant concentration of germanium and to have a substantially constant concentration of carbon. As an example, the second portion of the second epitaxial layer can have a constant germanium concentration of approximately 20 to 25 percent and can also have a constant carbon concentration of less than approximately 0.1 percent to approximately 0.3 percent. In the preferred embodiment, the germanium and carbon concentrations in the second portion of the second epitaxial layer are the same as the germanium and carbon concentrations, respectively, in the first portion of the second epitaxial layer. Also in the preferred embodiment, the second portion of the second epitaxial layer has a thickness of approximately 5 to 10 nanometers. Further in the preferred embodiment, the second portion of the second epitaxial layer is grown at the same temperature as the first portion of the second epitaxial layer.

At a step 130 of method 100 in FIG. 1, a third portion of the second epitaxial layer is grown over the second portion of the second epitaxial layer in the chamber of the epitaxial growth reactor. The third portion of the second epitaxial layer is comprised of silicon, germanium, and carbon and can be optionally comprised of the p-type dopant. The third portion of the second epitaxial layer can be grown at a rate of approximately 0.05 to 0.15 nanometers per second and can have a thickness of greater than approximately 1 nanometer. The third portion of the second epitaxial layer can be grown at a temperature of approximately 590 to 650 degrees Celsius.

In the preferred embodiment, the third portion of the second epitaxial layer is grown on the second portion of the second epitaxial layer to consist essentially of silicon, germanium, and carbon. The third portion of the second epitaxial layer can be grown from a silicon gas source such as silane, disilane, or dichlorosilane, a germanium gas source such as hydrogen germane, and a carbon gas source such as methylsilane. Also in the preferred embodiment, the third portion of the second epitaxial layer is grown to be substantially devoid of the p-type dopant, to have a substantially constant concentration of germanium, and to have a substantially constant concentration of carbon. As an example, the third portion of the second epitaxial layer can have a constant germanium concentration of approximately 5 to 15 percent and can also have a constant carbon concentration of less than approximately 0.1 percent to approximately 0.3 percent. In the preferred embodiment, the carbon concentration in the third portion of the second epitaxial layer is the same as the carbon concentrations in the first and second portions of the second epitaxial layer, but the germanium concentration in the third portion of the second epitaxial layer is different from and is less than the germanium concentration in the first and second portions of the second epitaxial layer. Further in the preferred embodiment, the third portion of the second epitaxial layer has a thickness of approximately 5 to 10 nanometers. Further in the preferred embodiment, the third portion of the second epitaxial layer is grown at the same temperature as the first and second portions of the second epitaxial layer.

At an optional step 135 of method 100 in FIG. 1, a fourth portion of the second epitaxial layer is grown over the third portion of the second epitaxial layer in the chamber of the epitaxial growth reactor. The fourth portion of the second epitaxial layer is comprised of silicon, germanium, and carbon and can be optionally comprised of the p-type dopant. The fourth portion of the second epitaxial layer can be grown at a rate of approximately 0.02 to 0.05 nanometers per second and can have a thickness of greater than approximately 1 nanometer. The fourth portion of the second epitaxial layer can be grown at a temperature of approximately 590 to 650 degrees Celsius.

In the preferred embodiment, the fourth portion of the second epitaxial layer is grown on the third portion of the second epitaxial layer to consist essentially of silicon, germanium, and carbon. The fourth portion of the second epitaxial layer can be grown from a silicon gas source such as silane, disilane, or dichlorosilane, a germanium gas source such as hydrogen germane, and a carbon gas source of methylsilane. Also in the preferred embodiment, the fourth portion of the second epitaxial layer is grown to be substantially devoid of the p-type dopant, to have a substantially constant concentration of germanium, and to have a substantially constant concentration of carbon. As an example, the fourth portion of the second epitaxial layer can have a constant germanium concentration of approximately 2 to 5 percent and can also have a constant carbon concentration of less than approximately 0.1 percent to approximately 0.3 percent. In the preferred embodiment, the carbon concentration in the fourth portion of the second epitaxial layer is the same as the carbon concentrations in the

first, second, and third portions of the second epitaxial layer, but the germanium concentration in the fourth portion of the second epitaxial layer is different from and is less than the germanium concentration in the first, second, and third portions of the second epitaxial layer. Further in the preferred embodiment, the fourth portion of the second epitaxial layer has a thickness of approximately 1 to 5 nanometers. Further in the preferred embodiment, the fourth portion of the second epitaxial layer is grown at the same temperature as the first, second, and third portions of the second epitaxial layer.

Next, a third epitaxial layer is grown over the second epitaxial layer at 140, 145. The third epitaxial layer serves as a capping layer over the second epitaxial layer. The third epitaxial layer is comprised of a semiconductor material different from the second epitaxial layer to create a heterojunction between the second and third epitaxial layers. In the preferred embodiment, the third epitaxial layer is comprised of silicon and a p-type dopant, but only a portion of the third epitaxial layer contains the p-type dopant. The p-type dopant in the third epitaxial layer is preferably the same as the p-type dopant in the second epitaxial layer. However, in an alternative embodiment, the p-type dopant in the third epitaxial layer can be different from the p-type dopant in the second epitaxial layer.

At a step 140 of method 100 in FIG. 1, a first portion of the third epitaxial layer is grown over the second epitaxial layer in the chamber of the epitaxial growth reactor. The first portion of the third epitaxial layer is comprised of silicon. The first portion of

the third epitaxial layer can be grown at a rate of approximately 0.1 to 0.4 nanometers per second and can have a thickness of greater than approximately 1 nanometer. The first portion of the third epitaxial layer can be grown at a temperature of approximately 690 to 710 degrees Celsius.

In the preferred embodiment, the first portion of the third epitaxial layer is grown on the second epitaxial layer to consist essentially of silicon. The first portion of the third epitaxial layer can be grown from a silicon gas source such as silane, disilane, or dichlorosilane. Also in the preferred embodiment, the first portion of the third epitaxial layer is grown to be substantially devoid of the p-type dopant. Further in the preferred embodiment, the first portion of the third epitaxial layer has a thickness of approximately 40 to 50 nanometers.

At a step 145 of method 100 in FIG. 1, a second portion of the third epitaxial layer is grown over the first portion of the third epitaxial layer in the chamber of the epitaxial growth reactor. The second portion of the third epitaxial layer is comprised of silicon and a p-type dopant. The second portion of the third epitaxial layer can be grown at a rate of approximately 0.1 to 0.4 nanometers per second and can have a thickness of greater than approximately 1 nanometer. The second portion of the third epitaxial layer can be grown at a temperature of approximately 690 to 710 degrees Celsius.

In the preferred embodiment, the second portion of the third epitaxial layer is grown on the first portion of the second epitaxial layer to consist essentially of silicon

and the p-type dopant. The second portion of the third epitaxial layer can be grown from a silicon gas source such as silane, disilane, or dichlorosilane and a p-type dopant gas source such as diborane. Also in the preferred embodiment, the second portion of the third epitaxial layer has a thickness of approximately 9 to 11 nanometers. Further in the preferred embodiment, the second portion of the third epitaxial layer is grown at the same temperature as the first portion of the third epitaxial layer.

Next, at a step 150 of method 100 in FIG. 1, the substrate with its epitaxial layers are unloaded or removed from the epitaxial growth reactor. After step 150, at a step 155 of method 100, the substrate and its epitaxial layers are annealed at a high temperature above room temperature. The annealing process of step 155 diffuses the germanium in the first, second, third, and fourth portions of the second epitaxial layer into a desired or predetermined distribution profile within the first, second, third, and fourth portions of the second epitaxial layer. As an example, a rapid thermal annealing (RTA) process can be used to perform step 155. This RTA process can be performed at approximately 1,000 to 1,050 degrees Celsius for approximately 10 to 30 seconds.

After the annealing process, the first portion of the second epitaxial layer may no longer consist solely of silicon, but may also comprise the p-type dopant diffused from the second portion of the second epitaxial layer. Similarly, the first portion of the second epitaxial layer may further comprise germanium after the annealing process. Other portions of the second epitaxial layer and other epitaxial layers may also be affected by the diffusion of elements from adjacent layers.

At a step 160 in method 100 in FIG. 1, the carbon in the second epitaxial layer is used to control the diffusion of the germanium in the second epitaxial layer. The carbon concentration in the second epitaxial layer does not merely affect the germanium diffusion during the annealing process of step 155, but is used to control the germanium diffusion to create or define a desired germanium profile within the second epitaxial layer. In addition to using the carbon concentration to control the germanium diffusion, the time and temperature of the annealing process are also used to control the germanium diffusion in the second epitaxial layer. Method 100 also includes other known manufacturing steps to complete the discrete HBT or the IC having the HBT.

FIG. 2 illustrates a cross-sectional view of a portion of a semiconductor component 200 manufactured by method 100 in FIG. 1. In particular, component 200 is illustrated immediately after step 160 in method 100 in FIG. 1. As illustrated in FIG. 2, component 200 includes a substrate 210 described in step 110 of method 100 in FIG. 1. Component 200 also includes a first epitaxial layer 220 described in step 115 of FIG. 1. Component 200 further includes a second epitaxial layer 230. Layer 230 has a first portion 231, a second portion 232, a third portion 233, and a fourth portion 234 described in steps 120, 125, 130, and 135, respectively, of FIG. 1. Component 200 additionally includes a third epitaxial layer 240. Layer 240 has a first portion 241 and a second portion 242 described in steps 140 and 145, respectively, of FIG. 1.

FIGs. 3 and 4 illustrate distribution profiles of germanium in epitaxial layer 230 of semiconductor component 100. The germanium distribution profiles before the anneal process of step 155 in FIG. 1 and after the anneal process of step 155 in FIG. 1 are illustrated in both of FIGs. 3 and 4. The germanium distribution profiles in FIGs. 3 and 4 are based on computer simulations.

FIG. 3 illustrates a graph having a horizontal or X axis representing a depth into component 200 of FIG. 1. The depth of zero microns on the X axis represents the top surface of layer 240 in FIG. 2. The graph in FIG. 3 also has a vertical or Y axis representing a concentration of germanium. The germanium distribution before and after the anneal process of step 155 in FIG. 1 is plotted along these two axes in FIG. 3. The germanium distribution in FIG. 3 is formed by method 100 when optional step 135 in FIG. 1 is not performed.

A box distribution profile 310 in FIG. 3 represents a pre-anneal or as-grown germanium distribution in the first and second portions of the second epitaxial layer of steps 120 and 125 in FIG. 1. A box distribution profile 320 in FIG. 3 represents a pre-anneal or as-grown germanium distribution in the third portion of the second epitaxial layer of step 130 in FIG. 1. A curved distribution profile 340 in FIG. 3 represents a post-anneal germanium distribution in the epitaxial layers and substrate of component 200 in FIG. 2. A curved distribution profile 350 in FIG. 3 represents a Secondary Ion Mass Spectrometry (SIMS) profile of the post-anneal germanium distribution in the

epitaxial layers and substrate of component 200 in FIG. 2. Profiles 340 and 350 are determined by computer simulations.

FIG. 4 illustrates a graph having a horizontal or X axis representing a depth into component 200 of FIG. 1. The depth of zero microns on the X axis represents the top surface of layer 240 in FIG. 2. The graph in FIG. 4 also has a vertical or Y axis representing a concentration of germanium. The germanium distribution before and after the anneal process of step 155 in FIG. 1 is plotted along these two axes in FIG. 4. The germanium distribution in FIG. 4 is formed by method 100 when optional step 135 in FIG. 1 is performed.

A box distribution profile 410 in FIG. 4 represents a pre-anneal or as-grown germanium distribution in the first and second portions of the second epitaxial layer of steps 120 and 125 in FIG. 1. A box distribution profile 420 in FIG. 4 represents a pre-anneal or as-grown germanium distribution in the third portion of the second epitaxial layer of step 130 in FIG. 1. A box distribution profile 430 in FIG. 4 represents a pre-anneal or as-grown germanium distribution in the fourth portion of the second epitaxial layer of step 135 in FIG. 1. A curved distribution profile 440 in FIG. 4 represents a post-anneal germanium distribution in the epitaxial layers and substrate of component 200 in FIG. 2. A curved distribution profile 450 in FIG. 4 represents a SIMS profile of the post-anneal germanium distribution in the epitaxial layers and substrate of component 200 in FIG. 2. Profiles 440 and 450 are determined by computer simulation techniques.

Therefore, an improved semiconductor component and method of manufacture is provided to overcome the disadvantages of the prior art. The method manufactures a semiconductor component by, among other steps, growing a doped silicon germanium: carbon (SiGe:C) epitaxial layer located over a semiconductor substrate, by annealing the epitaxial layer, and by using the carbon in the epitaxial layer to control diffusion of the germanium in the epitaxial layer during the annealing step. The epitaxial layer is preferably formed by growing the epitaxial layer with a substantially constant carbon concentration and two or three substantially constant germanium concentrations. The epitaxial layer is preferably not grown by using more than three constant germanium concentrations. The number of germanium concentration steps is kept low to facilitate the matching of different epitaxial growth reactors, to increase the throughput for the process, and to keep the cost and complexity of the process at a minimum. The epitaxial layer is also preferably not grown by using a non-constant or continuously variable germanium concentration for the same reasons.

Although the invention has been described with reference to specific embodiments, it will be understood by those skilled in the art that various changes may be made without departing from the spirit or scope of the invention. For instance, the numerous details set forth herein such as, for example, the material compositions, the chemical concentrations, and the layer thicknesses are provided to facilitate the understanding of the invention and are not provided to limit the scope of the invention. Furthermore, the p-type dopant in the second epitaxial layer can be replaced by an n-

type dopant if the HBT is a PNP transistor. Accordingly, the disclosure of embodiments of the invention is intended to be illustrative of the scope of the invention and is not intended to be limiting. It is intended that the scope of the invention shall be limited only to the extent required by the appended claims.

CLAIMS

1. A method of manufacturing a semiconductor component comprising:

providing a semiconductor substrate (210);

growing an epitaxial layer (230) comprised of silicon, germanium, carbon, and a p-type dopant located over the semiconductor substrate;

annealing the epitaxial layer; and

using the carbon in the epitaxial layer to control diffusion of the germanium in the epitaxial layer while annealing the epitaxial layer.

2. The method of claim 1 wherein:

using the carbon further comprises:

using the carbon to define a distribution profile of the germanium in the epitaxial layer.

3. The method of claim 1 or 2 wherein:

growing the epitaxial layer further comprises:

increasing a concentration of the carbon in the epitaxial layer to increase a diffusion length of the germanium.

4. The method of claim 1 or 2 wherein:

growing the epitaxial layer further comprises:

decreasing a concentration of the carbon in the epitaxial layer to decrease a diffusion length of the germanium.

5. The method of claim 1 or 2 or 3 or 4 wherein:

growing the epitaxial layer further comprises:

growing a first portion of the epitaxial layer having a first concentration of the germanium; and

growing a second portion of the epitaxial layer located over the first portion of the epitaxial layer and having a second concentration of the germanium.

6. The method of claim 5 wherein:

growing the epitaxial layer further comprises:

providing the second concentration of the germanium less than the first concentration of the germanium.

7. The method of claim 5 or 6 wherein:

growing the epitaxial layer further comprises:

growing at least the first portion of the epitaxial layer to be comprised of the p-type dopant.

8. The method of claim 5 or 6 or 7 wherein:

growing the epitaxial layer further comprises:

growing a third portion of the epitaxial layer located over the second portion of the epitaxial layer and having a third concentration of the germanium.

9. The method of claim 8 wherein:

growing the epitaxial layer further comprises:

providing the third concentration of the germanium less than the second concentration of the germanium; and

providing the second concentration of the germanium less than the first concentration of the germanium.

10. The method of claim 5 or 6 or 7 or 8 or 9 wherein:

growing the epitaxial layer further comprises:

growing the first portion of the epitaxial layer with a substantially constant concentration of the carbon; and

growing the second portion of the epitaxial layer with the substantially constant concentration of the carbon.

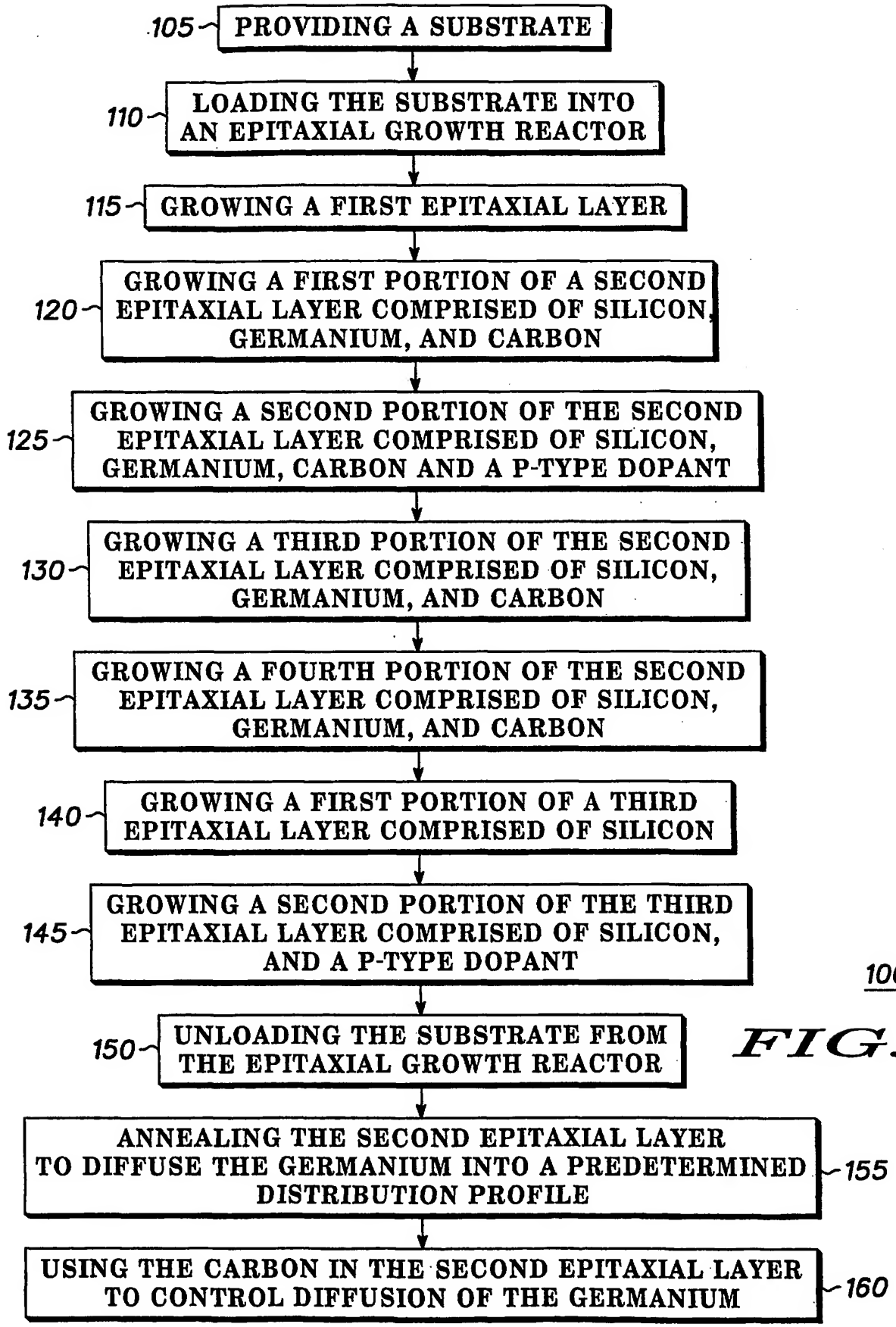
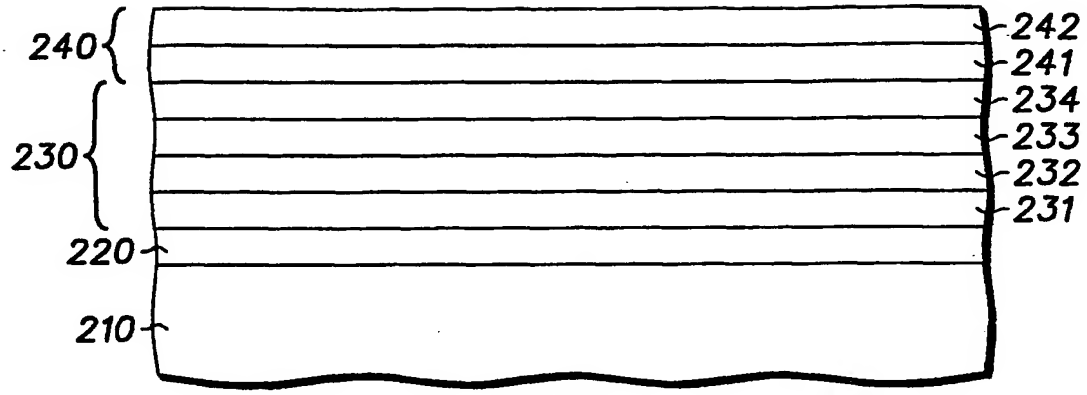


FIG. 1



200 FIG. 2

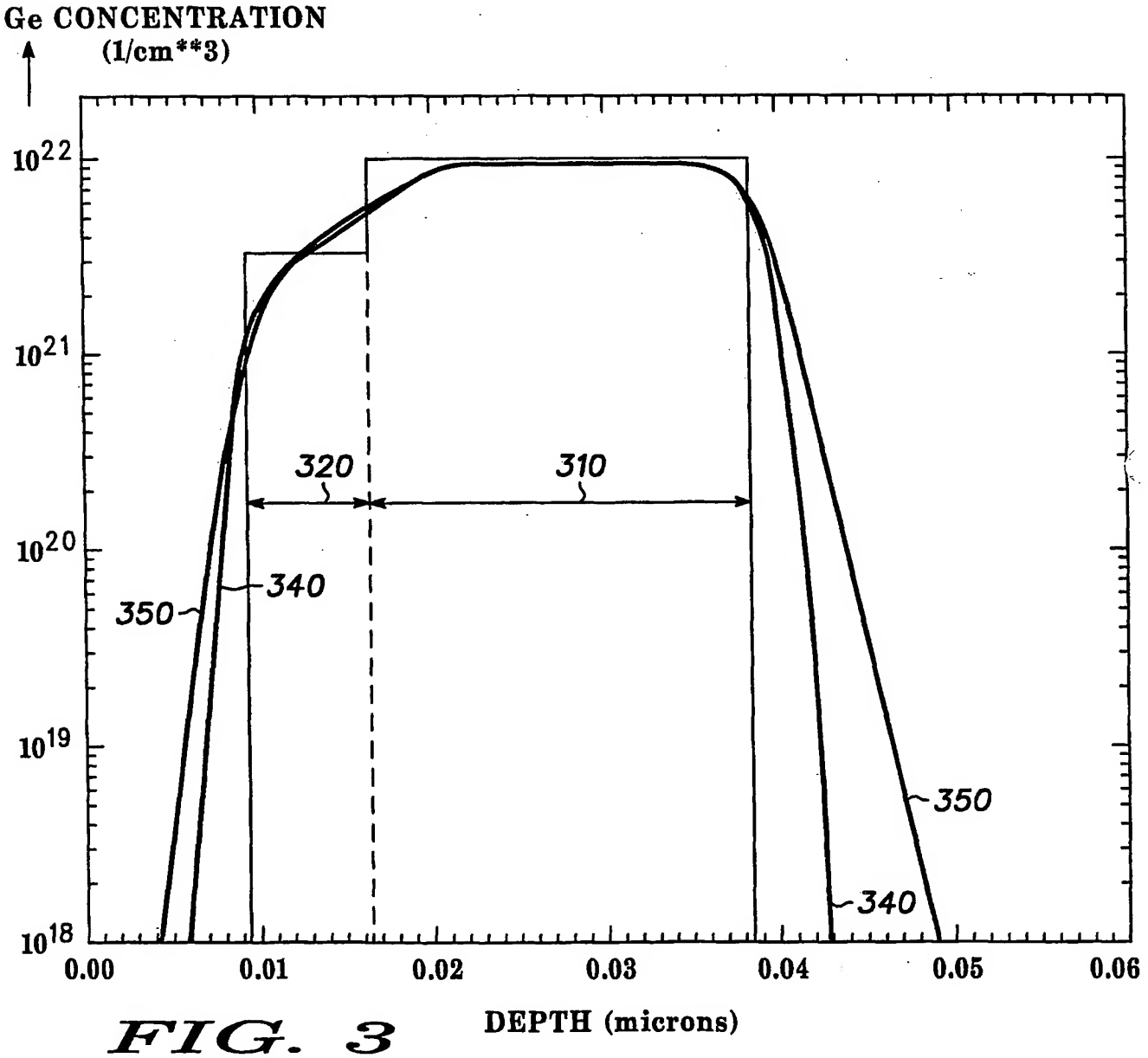


FIG. 3

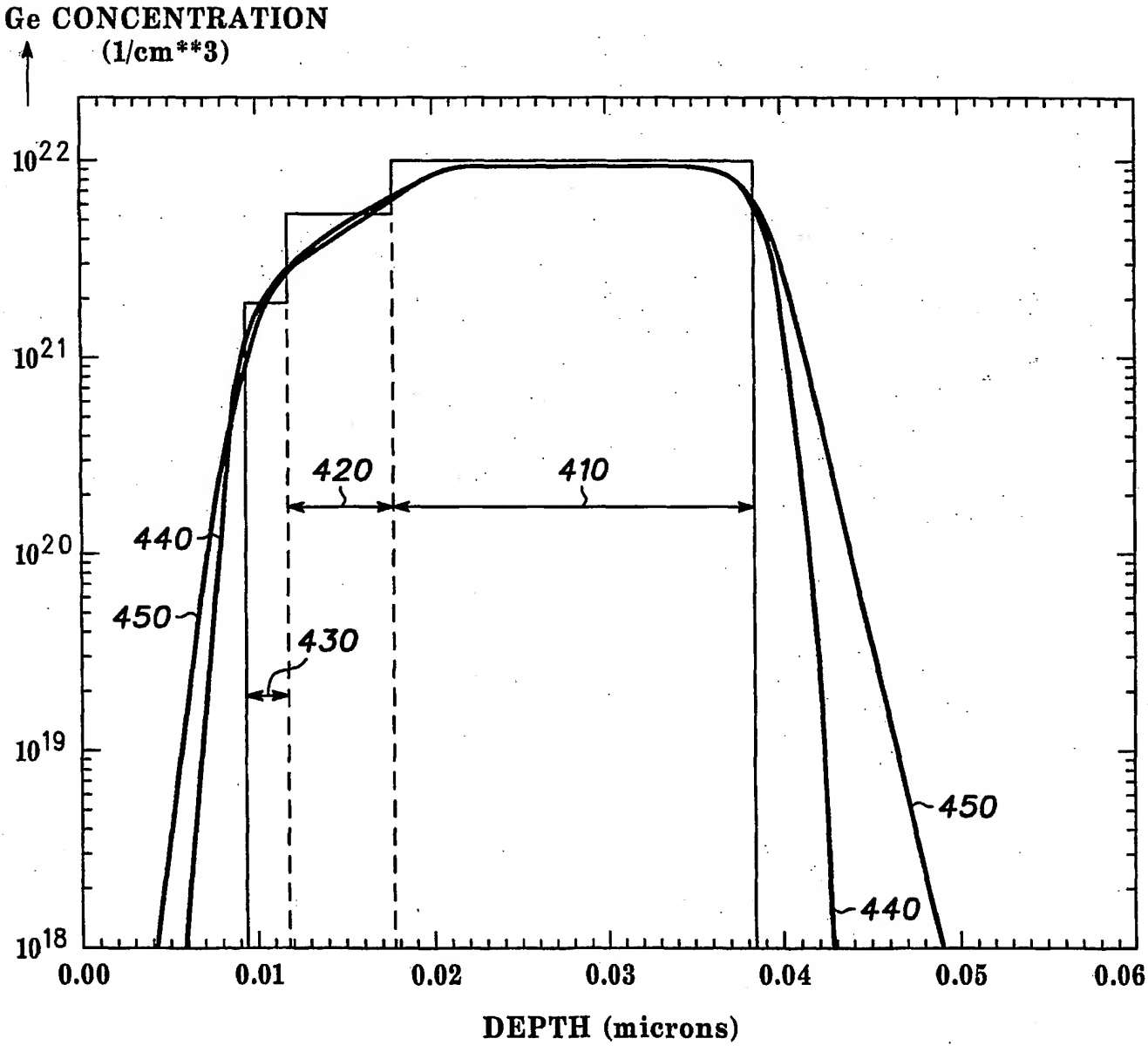


FIG. 4

INTERNATIONAL SEARCH REPORT

Int[illegible]nal Application No
PC., JS 01/16689

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L21/331

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, INSPEC, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,Y	EP 1 065 728 A (MATSUSHITA ELECTRIC IND CO LTD) 3 January 2001 (2001-01-03) abstract; figures 7A,8A,9A	1-10
Y	ZAUMSEIL P, FISHER G.G, BRUNNER K, EBERL K: "Comparison of the thermal stability of Si0.603Ge0.397/Si and Si0.597Ge0.391C0.012/Si superlattice structures" JOURNAL OF APPLIED PHYSICS, vol. 81, no. 9, 1 May 1997 (1997-05-01), page 6134 XP002182253 abstract	1-10
Y	WO 98 26457 A (HEINEMANN BERND ;LIPPERT GUNTHER (DE); INST HALBLEITERPHYSIK GMBH) 18 June 1998 (1998-06-18) claim 7; figure 6	1-10

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
7 November 2001	28/11/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Le Meur, M-A

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INTERNATIONAL SEARCH REPORT

Inte nal Application No
PC1/uS 01/16689

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	LANZEROTTI L D ET AL: "SUPPRESSION OF BORON OUTDIFFUSION IN SIGE HBTS BY CARBON INCORPORATION" INTERNATIONAL ELECTRON DEVICES MEETING 1996. TECHNICAL DIGEST.IEDM 96. SAN FRANCISCO, DEC. 8 - 11, 1996, INTERNATIONAL ELECTRON DEVICES MEETING (IEDM), NEW YORK, IEEE, US, 8 December 1996 (1996-12-08), pages 249-252, XP000753756 ISBN: 0-7803-3394-2 figure 1B	1-10
A	RUCKER H ET AL: "Tailoring dopant diffusion for advanced SiGe:C heterojunction bipolar transistors" SOLID STATE ELECTRONICS, ELSEVIER SCIENCE PUBLISHERS, BARKING, GB, vol. 44, no. 5, May 2000 (2000-05), pages 783-789, XP004191709 ISSN: 0038-1101 page 783, right-hand column, line 13 - line 18 page 789, left-hand column, line 1 - line 10	1-10
A	ZAUMSEIL P ET AL: "X-RAY DIFFRACTION STUDIES OF THE INFLUENCE OF SUBSTITUTIONAL CARBONON SI/GE INTERDIFFUSION IN SIGE/SI SUPERLATTICES" DIFFUSION AND DEFECT DATA. SOLID STATE DATA. PART B, SOLID STATE PHENOMENA, VADUZ, LI, vol. 69/70, 1999, pages 203-208, XP001035190 ISSN: 1012-0394 abstract	1-10

INTERNATIONAL SEARCH REPORT

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PC1/US 01/16689

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		JP 2001068479 A	16-03-2001
WO 9826457 A	18-06-1998	DE 19652423 A1	10-06-1998
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Form PCT/ISA/210 (patent family annex) (July 1992)